Draft

ADVISORY BOARD ON
RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

SC&A EVALUATION OF NIOSH WHITE PAPER, "METHOD TO ASSESS INTERNAL DOSE USING GROSS ALPHA, BETA, AND GAMMA BIOASSAY AND AIR SAMPLING AT THE LAWRENCE BERKELEY NATIONAL LABORATORY"

Contract No. 211-2014-58081
SSCA-TR-2018-SP003, Revision 0

Prepared by

Robert Barton, III, CHP
Ron Buchanan, PhD, CHP
Joyce Lipsztein, PhD

SC&A, Inc.
2200 Wilson Boulevard, Suite 300
Arlington, VA 22201-3324

Saliant, Inc.
5579 Catholic Church Road
Jefferson, MD 21755

April 2018

SC&A, INC.: ***Technical Support for the Advisory Board on Radiation and Worker Health Review of NIOSH Dose Reconstruction Program***

DOCUMENT TITLE:	SC&A Evaluation of NIOSH White Paper, "Method to Assess Internal Dose Using Gross Alpha, Beta, and Gamma Bioassay and Air Sampling at the Lawrence Berkeley National Laboratory"
DOCUMENT NUMBER/ DESCRIPTION:	SCA-TR-2018-SP003
REVISION NO.:	0 (Draft)
SUPERSEDES:	N/A
EFFECTIVE DATE:	April 18, 2018
TASK MANAGER	Joe Fitzgerald, MS, MPH [signature on file]
PROJECT MANAGER:	John Stiver, MS, CHP [signature on file]
DOCUMENT REVIEWER(S):	Joe Fitzgerald, MS, MPH [signature on file] John Stiver, MS, CHP [signature on file]

Record of Revisions

Revision Number	Effective Date	Description of Revision
0 (Draft)	4/18/2018	Initial issue

TABLE OF CONTENTS

ABBREVIATIONS AND ACRONYMS

ABRWH	Advisory Board on Radiation and Worker Health
BZ	breathing zone
BZA	breathing-zone air
C	carbon
cpm	counts per minute
DOE	U.S. Department of Energy
dpm	disintegrations per minutes
Er	erbium
GA	general air
GM	Geiger-Müller tube
H	hydrogen
I	iodine
ICRP	International Commission on Radiological Protection
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
MeV	mega-electron volt
MPC	maximum permissible concentration
NIOSH	National Institute for Occupational Safety and Health
NUMEC	Nuclear Materials and Equipment Corporation
ORAUT	Oak Ridge Associated Universities Team
P	phosphorus
pCi/m^3	picocuries per cubic meter
SEC	Special Exposure Cohort
SRDB	Site Research Database
TBD	technical base document
U	uranium
USDHEW	U.S. Department of Health Education and Welfare

1 INTRODUCTION AND BACKGROUND

On September 18, 2017, the National Institute for Occupational Safety and Health (NIOSH) issued a white paper, *Method to Assess Internal Dose Using Gross Alpha, Beta, and Gamma Bioassay and Air Sampling at the Lawrence Berkeley National Laboratory* (NIOSH 2017a, referred to as "the white paper"). This report is SC&A's evaluation of that white paper.

2 SUMMARY OF WHITE PAPER

The purpose and overall methodology is summarized on page 6 of the white paper as follows:

> *This white paper provides methods for assessing internal dose using gross alpha, gross beta, and gross gamma bioassay results and air sampling data at Lawrence Berkeley National Laboratory (LBNL). Methods are provided for assessing gross alpha, gross beta, and gross gamma results bioassay results that are below and above the minimum detectable activity. Air sampling data is used to assign internal dose from shorter-lived radionuclides that may not be detected by bioassay. In addition, a method is provided for assigning internal dose to an unmonitored worker using air sampling data. Example calculations are provided validating the proof of concept. This method would apply for 1962 and later. The methods described in this white paper will need to be implemented in an internal dose tool.*

The white paper essentially recommends a method of applying recorded air sample and bioassay sample results, obtained using gross-count data (where the specific radionuclides may not identified), to the many possible radionuclides present at LBNL to derive intake values and then assigning the maximum feasible dose to the organ or tissue of interest for 1962 and later years.

2.1 DATA USED IN WHITE PAPER

Table 1, page 10, is the main source of data used in the white paper. This table lists the 95th percentile annual air concentration for alpha and beta/gamma emitters in picocuries per cubic meter (pCi/m^3) for the period 1962–1993. Additionally, the white paper addresses the use of bioassay data, if available. All intake and dose calculations in the white paper are based on air samples and bioassay samples. Note that the data in Table 1 are not radionuclide specific, and that the concentrations for beta emitters and gamma emitters are combined and not listed separately.

2.2 MAJOR ITEMS CONSIDERED IN WHITE PAPER

NIOSH considered the following items in the methodology used in the white paper:

- Radionuclides with half-lives less than 20 hours (Table 2, page 11, for beta and gamma)
- Radionuclides with half-lives between 20 hours and 100 days (Table 9, pages 20–22 for alpha, beta, and gamma emitters)

- Radionuclides with half-lives greater than 100 days (Table 4, page 14, for alpha emitters, Table 6, page 16, for beta emitters, and Table 8, page 19, for gamma emitters)
- Branching factors of the emitted radiation (Table 3, page 12, for alpha emitters, Table 5, page 15, for beta emitters, and Table 7, page 17, for gamma emitters).

3 SC&A'S EVALUATION

3.1 ITEMS NOT ADDRESSED IN WHITE PAPER

While the white paper did a commendable job of addressing many aspects of applying gross alpha, beta, and gamma results to dose reconstruction, SC&A found that the following technical issues were not sufficiently addressed.

3.1.1 Air Samples May Not Represent Concentrations Breathed by Workers

The white paper states (NIOSH 2017a, page 7):

> *These air samples were also called breathing-zone (BZ) air samples, but were actually work area air samples.*
>
> *The limitations of work area air sampling were recognized in the early days at LBNL. Air samplers did not normally reflect general room area atmosphere, but only a closely circumscribed volume near the sampling head (Thaxter 1955). Lawrence Berkeley National Laboratory (*[LBNL 1981]*) noted:*
>
> > ***Our air samples are not good representative samples of breathing air.*** *Air currents are so unpredictable that air even a few inches away from a person's nose can be quite different from that which he breathes. Air samples give only a rough idea of an individual's exposure, and for that reason, any radioactivity detected should be taken seriously, even if only a small fraction of MPC.* [Emphasis added.]

A LBNL document, *Air Monitoring – UCRL Berkeley*, August 24, 1955 (Thaxter 1955) states:

> *Possibly one of the most important limitations resides in the fact that the air sampled is that within a few inches of the sampling tube opening. Thus final readings do not normally reflect general room atmosphere but only a closely circumscribed volume near the sampling head. Thus a sampling at bench level will not tell you what the chemist breathed, necessarily.*

The white paper refers to three types of air samples: room air, work area air (air sampler situated near the work), and BZ air. The use of the term "room air" is found once on page 91, the use of the term "work area air" is found twice on page 7, and the term "BZ air" is used throughout the white paper. It appears that the term BZ air is used when actually the air sample results could have been from room or work area sampling.

The fact that results from air sampling do not always represent BZ air concentrations has also been documented at other U.S. Department of Energy (DOE) sites and is the subject of International Commission on Radiological Protection (ICRP) Publication 130, *Occupational Intakes of Radionuclides: Part 1* (ICRP 2015). Examples of concerns about representativeness include the following:

1. The NUMEC site profile, ORAUT-TKBS-0041, *Site Profile for Nuclear Materials and Equipment Corporation, Apollo and Parks Township, Pennsylvania*, Revision 04 (NIOSH 2017b), states (page 50):

   > *Fifty percent of the lapel air sample results at the Apollo site showed concentrations 7 times greater than stationary air samples. The median of the ratio of lapel BZA to GA concentration results was found to be about 7 at the Apollo and Parks Township sites.*

2. Lawrence Livermore National Laboratory (LLNL) was a sister laboratory of LBNL and was also administered by the University of California. NIOSH's evaluation of the LLNL air sampling program indicates that air monitoring data were not representative of the workers' BZ air and were a factor in granting the LLNL Special Exposure Cohort (SEC) for the period 1974–1989. NIOSH stated in a 2016 presentation to the Advisory Board (NIOSH 2016):

   > *NIOSH has determined the available air monitoring data from Building 251 may not be adequately representative of the worker breathing zones, and are consequently not considered sufficient for Building 251 dose reconstruction during the period 1974–1989.*

3. SC&A's evaluation of using room air sampling at the Argonne National Laboratory-West is provided in a memorandum of July 14, 2016. In that memorandum, SC&A points out that room air samples do not generally represent the air concentration breathed by workers (SC&A 2016).

4. ICRP Publication 130 (ICRP 2015, page 98) summarized the problem:

   > *Breathing zone measurements can vary significantly as they can be affected by measurement conditions such as orientation of the sampler with respect to source, on which lapel (right or left) the sampler is worn, design of the air sampling head, particle size, local air velocity and directions and sharp gradients in and around the breathing zone of workers.*

   ICRP Publication 130 (ICRP 2015) cites studies that show that personal air sample data can be used to obtain satisfactory estimates of intakes for groups of workers. However, for individuals, personal air samplers (PAS) lack correlation between personal air sampler results and bioassay-based intake estimate for known acute exposures. Static air sampling can underestimate concentrations in air in the BZ of a worker; therefore,

personal air sampler/static air sampling air concentrations can vary from less than 1 up to 50, depending on the nature of the work.

Therefore, SC&A has the following finding:

Finding 1: Air Samples May Not Represent Concentrations Breathed by Workers – It appears that the white paper uses the terms BZ, room air, and work area air samples interchangeably. However, as indicated in the quoted LBNL documents above, room air or work area air samples may not represent the radionuclide concentrations in the BZ of workers. This is a problem that has been recognized at other DOE sites and applies to LBNL also. The use of room air or work area air samples could lead to a sufficient underestimate of the worker's intakes when the worker is located close to the source and the air sampler is located elsewhere.

3.1.2 Technical Issues with Gross Counting Data Conversion to Concentration for Use in Dose Reconstruction

It appears from the white paper that the air concentration values (pCi/m^3) listed in Table 1, page 10, were obtained from LBNL records that listed the air concentration values in pCi/m^3, or maximum permissible concentration (MPC) values (from which the pCi/m^3 values were derived). The original counts per minute (cpm) results obtained from the counting equipment after counting the air samples were converted to disintegrations per minute (dpm). The pCi/m^3, or percent of MPC, values were then obtained from these derived dpm values and the total air volume. The original conversion from cpm to dpm was based on an assumed radionuclide being counted, with an assigned efficiency at the time of counting using some standard for calibration (e.g., uranium-235 [U-235], strontium-90, etc.). The backscatter, sample self-absorption, air and window absorption, and detector intrinsic efficiency will vary depending on the radionuclide present, even if all the physical counting parameters remain constant. The many different radionuclides used to assign dose in the white paper have varying energies: approximate energy ranges are alpha 4.5 mega-electron volts (MeV) to 6.5 MeV, beta 0.010 MeV to 0.3 MeV median energy (0.020 MeV to 2 MeV maximum energy), and photons from x-rays to approximately 2 MeV. Therefore, the resulting counting efficiency (cpm to dpm conversion factor) would vary according to the energy of the radiation (i.e., radionuclide), creating an issue with using a recorded dpm value, obtained under an assumed radionuclide, and assigning it to another radionuclide with a different energy emission spectra. This same analysis applies to bioassay results that were obtained from gross alpha, beta, or gamma counting of bioassay samples.

SC&A analyzed the characteristics of the radiation detectors generally in use at the time the samples were counted and found that the type of radionuclide counted could influence the counting results by a factor of 2 to 10, depending on the energy and type of radiation (alpha, beta, or gamma) present. For the period of interest, it was assumed that the type of detectors in use were ionization chambers, gas-flow proportional counters, or Geiger-Müller (GM) tubes for gross alpha or beta/gamma counting. Sodium-iodide (NaI) or germanium-lithium (Ge(Li)) detectors would have been used for gamma-only counting. The following is a brief discussion of the dependence of the efficiency of a gross counting system as a function of the type and energy of the radiation emitted.

Alpha – Sample, Air, and Window Attenuation versus Energy of Alpha Particles

Alpha particles are helium nuclei with a +2 charge and have relatively low penetrating power compared to betas and photons. Therefore, material located between the point of emission inside the sample and the sensitive volume of the detector will decrease the chances of the alpha particle being counted. The more energetic the alpha particle, the more likely it will penetrate the sample material and air/window to reach the detector's sensitive volume to be counted. Therefore, all other physical parameters remaining constant, radionuclides with the more energetic alpha particles are more likely to be counted. Because of the relatively large mass and low penetrating power of alpha particles, backscatter from the sample holder and surrounding structures is generally not an important function of alpha energy.

Alpha particle energies for radionuclides listed in the white paper range from approximately 4.5 MeV to 6.5 MeV. According to the information in the *Radiological Health Handbook*, Revised Edition (USDHEW 1970, page 125), the range of alpha particles in air (which would be a first-order indicator for other materials as well) increases by a factor of approximately 2 when going from 4.5 MeV alphas to 6.5 MeV alphas. Therefore, if the detector was calibrated using a radionuclide standard emitting 6 MeV alphas but was actually counting an air or bioassay sample emitting 4.5 MeV alphas, the reported dpm could be understated for the lower energy (4.5 MeV) alpha-emitting radionuclide because of the sample thickness and any air/window materials, if present.

Beta – Sample and Window Attenuation and Backscatter versus Energy of Beta Particles

Beta particles are energetic electrons with a -1 charge and have medium penetrating power compared to alpha particles and photons. Therefore, material located between the point of emission inside the sample and the sensitive volume of the detector will decrease the chances of the beta particle being counted. The more energetic the beta particle, the more likely it will penetrate the sample material and detector window to reach the detector's sensitive volume to be counted. Therefore, all other physical parameters remaining constant, radionuclides with the more energetic beta particles are more likely to be counted. Additionally, because of the relatively small mass and medium penetrating power of beta particles, backscatter from the sample holder and surrounding structures is a function of beta energy.

The beta particles listed in the white paper have a range of approximately 0.010 MeV to 0.300 MeV of median energy (range of approximately 0.020 MeV to 2 MeV maximum energy). Some Site Research Database (SRDB) documents cited in the white paper provide brief snapshots of the beta gross counting procedures used at LBNL during the period of interest. A 1964 University of California at Berkeley *Manual of Instructions, Automatic Processing of Airborne Activity Data* (Peck 1964, pages 29 and 30), states that the beta/gamma counting for Filter-Queen air samples was performed using a GM tube and that the efficiency of the GM tube was a function of beta energy, with a median value of 0.6 MeV used for standardization (SC&A assumes that this means the beta calibration standard had a median beta energy of 0.6 MeV). The manual gives the beta/gamma efficiency for the hand counter as 5% and the automatic counter as 3%. For the stack membrane air filter, the manual gives the alpha efficiency as 47.4 % (no alpha energy provided), with a beta/gamma efficiency of 12.1%. For the stack charcoal samples, the manual gives the beta/gamma efficiency as 12.1% ÷ 2 = 6.05%. These changes in efficiencies

indicate that the detector efficiency is an important function of the sample material and thickness and hence would be dependent on the particle's energy.

A 1965 radiochemistry analysis report by the LBNL Health Chemistry Department (LBNL 1965, PDF page 15) states that the effective beta energy used in the analysis of the Filter Queen filters was 1.3 MeV (in contrast to the median beta energy of 0.6 MeV stated in Peck 1964). A 1966 Health Chemistry *Report of Special Analysis* states that "*There is a reasonably good fit, although our points lead to a slightly different shape* [curve]. *The discrepancy is very likely* ***due to energy dependence in the response of our GM counter***" (emphasis added) (LBNL 1966, PDF page 94).

The following summary indicates some of the parameters that determine the detection efficiency of beta-particle counting systems. These parameters could influence the conversion of cpm to dpm for different energy beta particles (compared to the radionuclide standard used to calibrate the counting system).

1. **Sample self-absorption –** The thicker the sample, the greater the amount of radioactive material it can contain. However, as the sample thickness increases, the fraction of the beta particles that escape the sample and interact with the detector's sensitive volume decreases. Therefore, for a given sample thickness, the beta counting efficiency decreases with decreasing beta energy. Sample self-absorption can range from negligible for beta particles in the 1 to 2 MeV range to around 50% for beta particles of 0.1 MeV (Price 1964, pages 132–134), depending on the sample material and thickness.

2. **Backscatter** – Backscatter is the result of a beta particle initially traveling in the opposite direction from the detector but then being scattered back into the detector by the sample backing material. The backscatter factor can range from 1.0 to 2, depending on the atomic number and thickness of the backing material the energy of the beta particle. The backscatter factor increases with increasing beta particle energy, increasing backing thickness, or increasing backing atomic number (Price 1964, pages 131 and 132).

3. **Window thickness** – The fraction of beta particles entering the detector's sensitive volume is a function of the energy of the beta particle and the material and thickness of the detector wall or window. The transmission of beta particles can range from a few percent for 0.250 MeV (calcium-45) betas, to near 100% for 1.707 MeV (phosphorus-32 [P-32]) betas (Price 1964, page 128)

4. **Detector intrinsic efficiency** – Once a beta particle reaches the sensitive volume of the detector, the probability of detection of the particle is near unity.

These beta counting parameters are all cumulative and decrease the system's counting efficiency as the energy of the beta particle decreases. Therefore, if the detector was calibrated using a radionuclide standard emitting relatively energetic beta particles (such as 0.6 MeV betas) but was actually counting an air or bioassay sample emitting a lower energy (such as 0.2 MeV betas), the reported dpm could be understated for the lower energy (0.2 MeV) beta-emitting radionuclide because of different transmission for the lower energy beta particles.

Gamma – Counter Efficiency versus Energy of Gamma Radiation

Gamma radiation from a given radionuclide generally consists of one or several mono-energetic photons per disintegration. Because of the relatively larger penetrating power of photons compared to charged particles, factors such as backscatter, sample thickness, and air attenuation are generally secondary issues for gamma detection, whereas the efficiency of the detector is the main concern.

Gamma Counting Using Gas-Filled Detectors

Gamma detection by gas-filled detectors depends upon the ability of the photon to pass through any wall or window of the detector to create secondary ions in the sensitive volume of the detector. Therefore, the overall efficiency of the detector is dependent upon the energy of the photon, the wall or window material, and the intrinsic efficiency of the detector. An example of this dependence is illustrated in Price 1964, page 138, which shows that the intrinsic efficiency of a gas-filled detector for photons increases by a factor of approximately 10 as the photon energy increases from approximately 0.200 MeV to 2.5 MeV. Therefore, if the detector was calibrated using a standard emitting 1.0 MeV photons but was actually counting an air or bioassay sample emitting 0.200 MeV photons, the reported dpm would be understated for the lower energy (0.200 MeV) photon-emitting radionuclide.

Gamma Counting Using Solid Detectors

Beyond the energy where the photon penetrates the housing or window of a solid detector (e.g., sodium-iodide or germanium-lithium), the detection efficiency decreases with increasing energy. An example of this is illustrated in a 1973 LBNL report, in which the counts per gamma response decrease by a factor of approximately 100 when going from 0.140 MeV to 1.33 MeV gamma-ray energy (LBNL 1973, PDF page 17). Therefore, if the gross-gamma detector was calibrated using a radiation standard emitting 0.662 MeV photons (e.g., cesium-137) but was actually counting an air or bioassay sample emitting 1.33 MeV photons (e.g., cobalt-60), the reported dpm was be understated for the greater energy (1.33 MeV) photon-emitting radionuclide in the sample.

Uncertainties Associated with Using Gross Count Data

These analyses indicate that the uncertainties associated with projecting intake values based on gross counting of air and/or bioassay samples are high and cannot be used to infer intakes and resulting doses with sufficient accuracy. Additionally, the uncertainties concerning the representativeness of air samples themselves are also high and were cited in NIOSH's white paper and outlined in SC&A's Finding 1 above. The combination of two results with a high degree of uncertainty does not yield results with lower uncertainty but instead creates a much larger overall uncertainty in attempting to project intake values.

The shortcomings of using gross counting of samples to project intakes were factors in granting the LLNL SEC for the period 1974–1989. NIOSH stated in a 2016 presentation to the Advisory Board (NIOSH 2016):

> *NIOSH has determined that it has insufficient information to verify that the routine* in vitro *bioassay program for Building 251 workers (combinations of analyses for gross alpha in urine, gross beta in urine, and plutonium in urine) was adequately sensitive for detection of U-233 intakes during the period 1974–1989.*

Therefore, SC&A has the following finding:

Finding 2: Technical Issues and Uncertainties with Gross Counting Data Conversion to Concentration/Intake for Use in Dose Reconstruction – Applying an air sample activity or bioassay sample activity, in units of recorded dpm or picocuries from gross counting, to different radionuclides for determining air concentrations or intakes, as proposed in the white paper, could lead to an underestimate of the intake because detector efficiency is dependent on the energy of the emitted radiation, and hence, the radionuclide, leading to large uncertainties.

3.1.3 Potentially Missed Radionuclides

As LBNL was a research laboratory with a wide range of projects and functions, it is difficult to ascertain that all the radionuclides that could result in assignable doses are included in the white paper. Although the white paper includes a large number of potential radionuclides, other radionuclides may have been present that were not accounted for in the white paper. For example, the white paper does not include any of the iodine radionuclides, but LBNL technical basis document (TBD) ORAUT-TKBS-0049, Revision 02, *Site Profile for the Lawrence Berkeley National Laboratory* (NIOSH 2010), includes radionuclides of iodine (i.e., iodine-123 [I-123], I-125, I-129, and I-131) as potential intakes in many of the tables. Additionally, two 1967 LBNL Health Chemistry reports (LBNL 1967a; LBNL 1967b) indicate that I-126 was being monitored and that 130 microcuries had been released. SC&A scanned the LBNL site profile and found other radionuclides listed that are not included in the white paper (e.g., erbium-165 [Er-165], Er-169, fermium-237, rhodium-102, and scandium-93).

Therefore, SC&A has the following observation:

Observation 1: Potentially Missed Radionuclides – It has not been demonstrated that the radionuclides listed in the white paper are all-inclusive of the potential radionuclides intakes at LBNL that are needed for adequate dose reconstruction for 1962 forward.

3.1.4 Incomplete Information in Claimants' DOE Files

The Introduction section of the white paper indicates the following approach concerning internal exposure potential for LBNL workers post-1961 (NIOSH 2017a, page 6):

> *Bioassay requests were generally made either once or twice per year for each employee in the bioassay program. Workers who worked with or in areas that contained unsealed radioactive materials typically received bioassays.... Therefore, based on the typical LBNL bioassay monitoring frequencies, a single bioassay result indicates that the worker had, at most, one year of internal exposure potential before the date of the bioassay…. **All other employment***

> ***periods with no bioassay indicate a potential exposure to environmental levels only.*** [Emphasis added.]

Table 4-2, Section 4.0, of the LBNL TBD (NIOSH 2010), provides the annual environmental intake rates for gross alpha, gross beta, tritium, and carbon-14 (C-14) that would presumably be used for claims with no indication of internal monitoring. However, in the example dose reconstruction beginning on page 27 of the white paper, it appears that unmonitored occupational doses would be assigned using the air sampling approach for a worker whose employment was only partially monitored internally (in the white paper example, the unmonitored period is assumed to occur from January 1, 1967, through December 31, 1968). Based on the introductory statements in the white paper and the subsequent dose reconstruction example, it appears that NIOSH assumed that a partially monitored worker is still considered a radiation worker and assigned unmonitored occupational internal doses based on the air sampling approach rather than the environmental intakes contained in the LBNL site profile.

However, the reliance on internal monitoring criteria to make such determinations is dependent on the effectiveness of appropriately identifying all relevant claimant-specific internal monitoring records and the inclusion of those records in the claimant's DOE-supplied dosimetry file. To evaluate the effectiveness of identifying internal monitoring records in the available claimant population, SC&A reviewed bioassay records captured by NIOSH and collected in SRDB References 21985 (LBNL 2006a), 21986 (LBNL 2006b), and 32378 through 32392 (LBNL 2007a through 2007o).[1] SC&A then compared bioassay records for identified claimants in the captured references to the DOE-supplied monitoring records for those individuals. Those DOE-supplied monitoring records represent the primary resource available to NIOSH in making determinations on internal dose assignment for individual dose reconstruction.[2]

SC&A identified 36 claimants among the captured bioassay records, which represented 719 internal monitoring results. While most of these results were attributed to tritium bioassays for a single claim (496 of 719 total samples), the remaining bioassay results represented a combination of gross alpha/beta/gamma urinalysis with occasional phosphorous, uranium, or thorium in vitro sampling. Of the 36 identified claimants with internal monitoring in the captured SRDB references, seven claim files did not reflect any of the corresponding internal monitoring records in the DOE-supplied monitoring files. These seven claims are described in Table 1 of this report. In four of the seven cases, internal monitoring was indicated to have occurred in the introductory letter provided by LBNL. However, the dates of these samples were not provided so that a comparison of intake rates based on bioassay and workplace air sampling could be made. In at least one of these cases, the referenced bioassay sample did not reflect the actual urinalysis sample identified in captured SRDB records (see Claim D). In the remaining three of seven reviewed cases, DOE indicates the energy employee was not monitored internally.

[1] SC&A identified and reviewed additional bioassay references in the SRDB; however (with rare exception), these additional files contained duplicate records that were in a different format.

[2] SC&A recognizes that NIOSH often supplements DOE-supplied monitoring records with additional captured records, such as the SRDB bioassay records referenced in this section. However, the completeness of such captured records has not been established; therefore, the reliance on supplemental records to fill in any gaps in an individual's monitoring record remains questionable.

Table 1. Description of Seven Claims with Deficiencies in Observed Internal Monitoring Records

Case Reference (Claim Number)	Missing Sample Type* (reason) and Date	Additional Comments
A ([redacted])	Alpha (periodic) – [redacted]/1962 Alpha (unspecified) – [redacted]/1963 Alpha (unspecified) – [redacted]/1964 Alpha (unspecified) – [redacted]/1965 Alpha (unspecified) – [redacted]/1966 Alpha (periodic) – [redacted]/1967	Introductory letter in DOE monitoring file indicates that six routine gross alpha samples were taken. However, no dates are provided and the specific records are not included.
B ([redacted])	Alpha (periodic) – [redacted]/1964	Introductory letter in DOE monitoring file indicates a single alpha sample was analyzed. However, no date is provided and the specific record is not included.
C ([redacted])	Whole Body Count (unspecified) – [redacted]/1978 Beta/Gamma/P-32 (unspecified) – [redacted]/1979 Beta/Gamma/P-32 (periodic) – [redacted]/1980 Beta/Gamma/P32 (periodic) – [redacted]/1981 Beta/Gamma/P-32 (periodic) – [redacted]/1982 Beta/Gamma/P-32 (periodic) – [redacted]/1983	DOE-supplied files indicate no internal monitoring exists for the claimant.
D ([redacted])	All (periodic) – [redacted]/1972	Introductory letter in DOE monitoring file indicates that only a gross alpha sample was conducted (no date supplied), and there was no indication of a gross beta or gross gamma analysis occurring. The observed sample was labelled as a "periodic sample."

Case Reference (Claim Number)	Missing Sample Type* (reason) and Date	Additional Comments
E ([redacted])	All/Uranium (periodic) – [redacted]/1976 All/Uranium (periodic) – [redacted]/1977 All/Uranium (periodic) – [redacted]/1978 Alpha/Uranium (special) – [redacted]/1978 All/Uranium (periodic) – [redacted]/1978 All/Uranium (periodic) – [redacted]/1979 All/Uranium (periodic) – [redacted]/1980 Uranium (unspecified) – [redacted]/1980 Uranium (unspecified) – [redacted]/1980 All/Uranium (periodic) – [redacted]/1981 C-14/H-3/P-32 (unspecified) - [redacted]/1981 Alpha/Uranium (special) – [redacted]/1982 All/Uranium (periodic) – [redacted]/1982 All/Uranium (periodic) – [redacted]/1983 Uranium (special) – [redacted]/1984 Thorium (special) – [redacted]/1984 All/Uranium (periodic) – [redacted]/1985 All/Uranium (periodic) – [redacted]/1986 All/Uranium (periodic) – [redacted]/1987 Uranium (special) – [redacted]/1988 All/Uranium (periodic) – [redacted]/1989 All/Uranium (periodic) – [redacted]/1990	DOE-supplied files indicate no internal monitoring exists for the claimant.
F ([redacted])	Thorium (periodic) – [redacted]/1992	The introductory letter in DOE monitoring file indicates that a single bioassay exists; however, the record was not included. The letter indicates the bioassay sample should be included with "other medical records." The sample was not located in Department of Labor case file.
G ([redacted])	Uranium (special) – [redacted]/1986	DOE-supplied files indicate no internal monitoring exists for the claimant. Observed uranium urine bioassay result is labelled as a "special" sample.

* Sample type "All" designates a gross alpha/beta/gamma urinalysis.

In addition to the seven claims described in Table 1, another six reviewed claims had at least some of the identified bioassay sampling records omitted from their respective DOE-supplied monitoring records. While the dose reconstruction example provided by NIOSH demonstrates that these six additional claimants would still be assigned occupational missed doses based on workplace air sampling, the omitted bioassay records illustrate the potential completeness limitations observed in available claimant-specific monitoring records. Given these limitations, the presence of internal monitoring results in DOE-supplied monitoring records may not be an appropriate metric for determining whether to assign occupational internal doses (i.e., missed doses based on workplace air sampling) as opposed to the ambient environmental intakes developed in the LBNL TBD (NIOSH 2010). Therefore, SC&A has the following observations:

Observation 2: Bioassays in Claimant DOE Files May Not Be Indicative of Exposure Potential – Given the observed limitations in ascribing internal monitoring data to an individual claimant, the presence of internal monitoring results in individual claim files may not be an appropriate criterion for determining whether occupational intakes should be applied in lieu of ambient environmental intakes. An alternate approach of assigning occupational intakes, unless clear evidence exists of "little to no exposure potential," would be more claimant favorable and consistent with dose reconstruction procedures for other sites.

Observation 3: Bioassays in Claimant DOE Files May Not Be Complete Compared to LBNL Documents – SC&A's sample analysis of 36 LBNL claims found that 13 of the DOE files for the 36 claims did not contain all the bioassay records indicated in the SRBD documents.

4 SUMMARY CONCLUSIONS

Although the white paper addressed many aspects of applying gross alpha, beta, and gamma results to dose reconstruction, SC&A found that some technical issues were not sufficiently addressed. SC&A's two findings include:

1. Air samples may not represent concentrations breathed by workers.

2. Technical issues and uncertainties with gross counting data conversion to concentration/intake for use in dose reconstruction.

SC&A had three observations:

1. Potentially missed radionuclides.

2. The bioassay records in claimant DOE files may not necessarily be indicative of exposure potential.

3. The bioassay records in the claimant DOE files may not be complete compared to LBNL documents.

5 REFERENCES

ICRP 2015. *Occupational Intakes of Radionuclides: Part 1*, ICRP Publication 130. Ann. ICRP 44(2).

LBNL 1965. *Report of Special Analysis*, Health Chemistry Department, Lawrence Berkeley National Laboratory, University of California, Berkeley, California. January 26, 1965. [SRDB Ref. ID 117675, PDF page 15]

LBNL 1966. *Report of Special Analysis: Fission Products in Samples off 11-7-66*, Health Chemistry Department, Lawrence Berkeley National Laboratory, University of California, Berkeley, California. December 8, 1966. [SRDB Ref. ID 117675, PDF page 94]

LBNL 1967a. *Report of Special Analysis: Environmental Gas Sampling, October 1967*, Health Chemistry Department, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. November 16, 1967. [SRDB Ref. ID 117675, PDF page 139]

LBNL 1967b. *Report of Special Analysis: Environmental Gas Sampling, November 1967*, Health Chemistry Department, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. December 14, 1967. [SRDB Ref. ID 117675, PDF page 143]

LBNL 1973. *Report of the Bioassay Laboratory, July 1972 through June 1973, Donner Laboratory*, LBL-2448, C.T. Schmidt, T.W. Sargent, D.J. Yaeger, and A.deG. Low-Beer, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. November 1973. [SRDB Ref. ID 71780]

LBNL 1981. *The Environmental Health and Safety Department Operational Guide for the Health and Safety Representative*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. December 1981. [SRDB Ref. ID 21984]

LBNL 2006a. *Individual Bioassay Reports for Employees Last Names Beginning with "A" (1965–1990)*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. January 13, 2006. [SRDB Ref. ID 21985]

LBNL 2006b. *Terminated Bioassay Results of Employees with Last Names Beginning with "A" (1961–1983)*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. January 13, 2006. [SRDB Ref. ID 21986]

LBNL 2007a. *Bioassay Cards January 4, 1960 – August 1, 1962 Card Numbers 1 through 407*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 23, 2007. [SRDB Ref. ID 32378]

LBNL 2007b. *Bioassay Cards Early Years (pre 1968) A through Z*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 23, 2007. [SRDB Ref. ID 32379]

LBNL 2007c. *Bioassay Cards to October 183 A & B, Radio-Chemical Assay Request Cards 1967–1983*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 23, 2007. [SRDB Ref. ID 32380]

LBNL 2007d. *Bioassay Cards to October 1983, C through F, Radio-Chemical Assay Request Cards*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 23, 2007. [SRDB Ref. ID 32381]

LBNL 2007e. *Bioassay Cards to October 1983, G through Mc, Radio-Chemical Assay Request Cards*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 23, 2007. [SRDB Ref. ID 32382]

LBNL 2007f. *Bioassay Cards to October 1983, Me through Z, Radio-Chemical Assay Request Cards*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 23, 2007. [SRDB Ref. ID 32383]

LBNL 2007g. *Bioassay Cards after October 1983, A through C, Radio-Chemical Assay Request Cards*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 23, 2007. [SRDB Ref. ID 32384]

LBNL 2007h. *Bioassay Cards after October 1983, D though G, Radio-Chemical Assay Request Cards*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 23, 2007. [SRDB Ref. ID 32385]

LBNL 2007i. *Bioassay Cards after October 1983, H through L, Radio-Chemical Assay Request Cards*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 23, 2007. [SRDB Ref. ID 32386]

LBNL 2007j. *Bioassay Cards after 1983, All of M, Radio-Chemical Assay Request Cards*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 23, 2007. [SRDB Ref. ID 32387]

LBNL 2007k. *Bioassay Cards after October 1983, N through R, Radio-Chemical Assay Request Cards*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA May 23, 2007. [SRDB Ref. ID 32388]

LBNL 2007l. *Film Badge Area Readings throughout Site 1956–1957*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 22, 2007. [SRDB Ref. ID 32389]

LBNL 2007m. *Bioassay Cards after 1983, All of S, Radio-Chemical Assay Request Cards*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 23, 2007. [SRDB Ref. ID 32390]

LBNL 2007n. *Bioassay Cards after October 1983, T through* [redacted]*, Radio-Chemical Assay Request Cards*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 23, 2007. [SRDB Ref. ID 32391]

LBNL 2007o. *Bioassay Cards after October 1983,* [redacted] *through Z, and Radio-Chemical Assay Request Cards*, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. May 23, 2007. [SRDB Ref. ID 32392]

NIOSH 2010. *Site Profile for the Lawrence Berkeley National Laboratory*, ORAUT-TKBS-0049, Revision 02, National Institute for Occupational Safety and Health, Cincinnati, OH. May 10, 2010.

NIOSH 2016. *Lawrence Livermore National Laboratory Special Exposure Cohort Evaluation Report*, presentation to the Advisory Board on Radiation and Worker Health, Tampa, Florida. March 24, 2016.

NIOSH 2017a. *Method to Assess Internal Dose Using Gross Alpha, Beta, and Gamma Bioassay and Air Sampling at the Lawrence Berkeley National Laboratory* [white paper], Revision 00, National Institute for Occupational Safety and Health, Cincinnati, OH. September 18, 2017.

NIOSH 2017b. *Site Profile for Nuclear Materials and Equipment Corporation, Apollo and Parks Township, Pennsylvania*, ORAUT-TKBS-0041, Revision 04, National Institute for Occupational Safety and Health, Cincinnati, OH. March 13, 2017.

Peck 1964. J.S. Peck, *Manual of Instructions, Automatic Processing of Airborne Activity Data*, JSP-777-62, Revised, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. January 24, 1964. [SRDB Ref. ID 137854]

Price 1964. W.J. Price, *Nuclear Radiation Detection*, Second Edition, McGraw-Hill Book Company, New York. 1964.

SC&A 2016. *Progress Report: ANL-W SEC-00224 Review, Strategy of Using the 10% Maximum Permissible Concentration Rule for Performing Dose Reconstruction*, memorandum to Idaho National Laboratory Work Group, SC&A, Inc., Vienna, VA, and Saliant, Inc., Jefferson, MD. July 14, 2016.

Thaxter 1955. M.D. Thaxter, Health Chemistry, *Air Monitoring – UCRL Berkeley*, MDT-980-55. August 24, 1955. [SRDB Ref. ID 21403, PDF pages 5–6]

USDHEW 1970. *Radiological Health Handbook*, Revised Edition, U.S. Department of Health Education and Welfare, Public Health Service, Rockville, MD. January 1970.